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METHODOLOGY OF THE INTEGRATED REGIONAL RISK ASSESSMENT AND ITS VERIFICATION IN PRACTICE

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Research article

Abstract: Index method enabling the complex risk assessment of region is described in the paper. The method is based on comparing critical indicators with acquired data. The data are then transformed into non-dimensional integrated indexes. Different risk spheres can be compared in this way. The method was applied for the health, environmental and technological risk assessments of the region.

Key words: Environment, Health, Index Value, Risk Assessment, Technological Risk.

Introduction

Communal integrated problem solving procedures are being pursued in the work of local authorities. These procedures ensure adequate quality and sustainable development of all the spheres of life. The implementation of measures and the development of activities supporting regional stability are inseparable prerequisites for achieving the required standard.

It is assumed to have a modern scientific information base for effective specialization and management of activities in a region. Knowledge of the current level of regional security is the important element significantly helping the public administration and the elected members of self-administration in their activities. Application of the suggested index system enables risk assessment within particular spheres of administrative and territorial units.

Materials and methods

The index method accepting the principles being used for the assessment of technological risks (Bozek, 2003; International Atomic Energy Agency, 1993; Lees, 1997) is the basis for the regional risk assessment. The preference identification of j-number of regional life interest spheres is assumed in the method. The interest spheres will be analyzed and assessed with the help of mostly specific procedures. The selected interest spheres are subjects to individual analysis (qualitative, semi quantitative and quantitative), generally on i-number of levels with q i number of elements on i-level.

In a complex security analysis it is possible to proceed in the following way. On a basic level the risk assessment is assumed from each one *q* element. The term risk generally reflects the relation between the seriousness of undesirable incident (its consequences) and the probability of its occurrence (Bate, 1993). If it is permitted by the pattern of risk, i.e. the impacts of different elements are analogical; the levels of individual risks are simply summed up:

$$R_{j.\,i} = \sum_{q=1}^{m} R_{j,\,i,\,q} \qquad \text{Eq. (1)}$$

where $R_{j.\,i}$ is a total risk in *j*-area on an *i*-level, $R_{j,\,i,\,q}$ is risk arising from *q*-element of *i*-level in *j*-area and *m* is a number of elements of *i*-level in *j*-area. Typical example of the above mentioned approach is the quantification of health risk in case of the mixture of priority carcinogenic pollutants occurring in the monitored area. At the same time the additive principle is considered, the synergic or antagonistic effects are not expected and the classification of carcinogens into genotoxic and epigenetic is ignored.

If the impact of undesirable incident is initiated by various factors and does not have additive character, the risk indexing is started already on this basic level. In the opposite case the indexing can be carried out on a higher level. An example from the area of health risks can be the risk of various types of virus diseases such as viral hepatitis, salmonelosis, meningococcal meningitis, bacillar disentery, scarlet fever, Lyme borrelia, measles, etc., the individual diseases can be caused by different factors (Hallenbeck, 1993).

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We suggest the indexation to be done in the field of real numbers and in interval <0; 5>, when the index:

0 - represents an unimportant, irrelevant risk;

1 - represents a marginal risk;

2 - represents an acceptable risk under the level of current standards;

3 - represents a tolerable risk, which should be gradually reduced;

4 - represents a significant risk over the level of current standards, which should be minimized immediately;

5 - represents an absolutely unacceptable risk.

The value of risk assessment index of *i*-level is then calculated as a weighted average of individual indexes (*i* - 1) of the level according to the following relation (2):

$$I_{j.i} = \sum_{x=1}^{k} w_{j,\,(i-1),\,x} \cdot I_{j,\,(i-1),\,x} \qquad \text{Eq. (2)}$$

where $I_{j.\,i}$ is an estimated risk index of *i*-level (e.g. incidence of infectious diseases) in *j*-area (health risk), $I_{j,\,(i\,-\,1),\,x}$ is the index of *x*-risk of (*i* - 1) level (e.g. the risk that viral hepatitis occurs) of *j*-area, $w_{j,\,(i\,-\,1),\,x}$ represents the index weight of *x*-risk of (*i* - 1) level of *j*-area and *k* represents the number of indexes of (*i* - 1) level (number of infectious diseases being assessed) in *j*-area.

The process continues in the same way over individual *i*-levels till the risk index of *j*-area is presented, which is shown in the following equation (3):

$$I_{j.} = \sum_{y=1}^{r} w_{j,\,(i=p),\,y} \cdot I_{j,\,(i=p),\,y} \qquad \text{Eq. (3)}$$

where I_j represents the risk index assessment in *j*-area, $I_{j,\,(i'=\,p),\,y}$ is *y*-risk index of *p*-level in *j*-area, $w_{j,\,(i\,=\,p),\,y}$ represents the weight of *y*-risk index of *p*-level of *j*-area, *r* represents the number of indexes of *p*-level of *j*-area, and finally *p* represents the number of levels of *j*-area being assessed.

Logical end of the given algorithm is the following formula (4) of the integrated risk index *I* in the region:

$$I = \sum_{j=1}^{s} w_j \cdot I_j \qquad \text{Eq. (4)}$$

where *I* is the assessment of the region integrated risk index, I_j is the risk index of *j*-area, w_j represents the weight of risk index of *j*-area and *s* represents the number of spheres (areas) being considered.

Results

It is clear from the above presented procedure, that risk indexes represent a non-dimensional quantity, which is derived from the risk assessment of the basic level elements. The risk assessment on a basic level has to be carried out with the help of the latest scientific findings, direct measurements, calculations, statistical data, sociological researches, or expert assessments. It is required to have a precise knowledge of the assessed area, risk assessment methods and the availability of wide range of identification data about an administrative unit or a territory.

The range and the multidisciplinary character of region risk assessment assumes a team co-operation of experts from different areas, it cannot be the outcome of an individual. The selection of both critical and safe limit values has to be made by experts on the basis of international, national and regional comparisons while accepting local conditions, or with the help of qualified assessments in such cases, when there is not enough data available.

The values of individual weights $w_{j,\,i,\,x}$ of *i*-level, *x*-index of *j*-sphere, or the index of weights w_j of risks in the assessed area *j*, represent the significance of indexes and they are determined either with the help of expert methods or in an analytical way.

It is recommended to use column graphs and possibly colourful earmarks for marking the contributions of individual level subareas (*i* - 1) for tabular interpretation of risks on individual levels and areas. It is also possible to use star graphs. The structure of analogical graphs will enable to analyze the efficiency of proposed measures after their introduction.

As far as the *s* range of the assessed areas is concerned, the selection is influenced by the site conditions and the intentions of competent administration authorities. We suggest the risk assessment in the following spheres as a possible alternative, which can be modified according to up to date requirements and local conditions:

A) nature;

B) health and environment;

C) technology;

D) economy;

E) social and mental sphere;

F) home politics;

G) psychology;

H) civilian protection;

J) information;

K) accommodation and housing policy;

L) crime;

M) terrorism;

N) military.

It is obvious that the proposed procedure enables to identify serious risks on each level and at the final stage to assess also the structure of risks in the region and its assessed areas. Regions can be then compared both on national and international levels. The outcomes also help the competent administrative authorities to initiate adequate measures and effectively target the activities in the regions.

Possible procedures in the health and technological risk assessment in a region are presented below. The area of technology was assessed independently. The monitored health risks subareas were as it follows:

I non-infectious diseases;

II infectious diseases;

III region zoonosis;

IV noise pollution;

V air quality;

VI traffic accident rate;

VII electromagnetic field;

VIII quality of surface waters from the recreational viewpoint;

IX quality of drinking water;

X healthy and quality food;

XI quality of soil in selected kindergartens;

XII waste management;

XIII accident rate among children and young people;

XIV quality of workplace.

The analysis of the demographic and health data available was the basis for the health risk assessment. The following data were analysed: selected demographic data, death rate caused by basic diseases, average life span, incidence of tumours and mortality caused by tumours, prevalence of diabetes and the incidence of selected diseases. The Geographic Information System was used for determining the risk impact on population (Vomacka, 2002).

It results from the analysis of demographic and selected health data in the subsphere of non-infectious diseases, that the situation in the region is comparable with the national average. By analysing chronic **non-infectious diseases**, such as heart and vascular diseases, tumours, metabolism diseases, allergies, etc. and with the help of formula (2) the index 4,0 was assessed for the above mentioned group of diseases. It is necessary to pay prime attention to the subgroup of tumours, especially the occurrence of colorectal carcinoma.

The occurrence analysis of selected **infectious diseases**, such as viral hepatitis, salmonelosis, meningococcal meningitis, bacillary disentery, scarlet fever, Lyme borrelia, measles, rubella, varicella, parotid gland, tick encephalitis and tularaemia, proved that the occurrence of diseases do not exceed national average. The index risk assessment of the above mentioned group of diseases is 2,9. It was recommended to improve basic hygienic habits, which are the prerequisite for the prevention of spreading infectious diseases.

Zoonoses are infectious diseases communicable from animals to humans. The following diseases were monitored in the infection risk analysis of selected zoonoses: rabies, tularaemia, leptospirosis, salmonelosis, ornithosis, brucellosis, anthrax, avian tuberculosis. The outcomes proved that infectious situation in the area of selected zoonoses in the region is extremely good and the index value 1,1 was determined by applying formula (2).

The measurement and assessment of **noise pollution** was carried out during day and night. Monitoring posts covered main communications on the territory of region. Total traffic volume was assessed in 15-minute intervals and the transit record included cars, light and heavy trucks, buses, trams, tractors and motorcycles. The noise measurement was carried out according to the elaborated methodology for the road traffic noise measurement. The outcomes were used for designing noise maps for day and night, elaborating the model of noise impact along the roads and assessing the negative impact of noise on particular number of inhabitants.

The outcomes of noise studies show that only a long term exposure to the current load can have a negative impact on a cardiovascular apparatus. The above mentioned subarea has got index 2,6. Objective information gained by measurement will be used in territorial planning, for describing current and prospective loads of outside areas, urban planning, designing changes including traffic routes and counter-noise measurements. Noise map is also an important source of information for planning and organization of regional traffic.

Air is one of the most important environmental elements and the **quality of air** is one of the most decisive factors affecting human health. It is known that adults breathe in approximately 30 $m^3.day^{-1}$ in average.

That is why special attention was paid to systematic monitoring of air quality. Car traffic pollutants were monitored on busy spots in relation

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to the measurement of roads trafficability and a noise map. Air measurements from three monitoring stations and three hygiene stations were included as well. Monitoring was focused on the concentration of ground ozone (the average monthly concentration varied from 64 to 86 $\mu g.m^{-3}$), NO_x, (average 167 $\mu g.m^{-3}$), SO_2, CO, CO_2 and air-borne dust.

The outcomes show that car traffic is the decisive element having a negative impact on air quality of the assessed region. It significantly contributes to the increased noise level, dust, ground O_3, NO_x and other elements of fume exhausts such as polycyclic aromatic hydrocarbons (PAH), volatile organic substance, CO, etc. Index 3,6 was calculated for air quality as a result of identified pollution of atmosphere and with the help of formula (2).

After analysing **traffic injury rate and transport service** on the territory of town the dangerous parts of road network were selected and classified. Statistic analysis of traffic accidents was carried out in these sectors and the outcomes were compared with national statistics. Transport service was checked also on the territories adjacent to the main road network. The analysis was made in two stages. Firstly the traffic accidents and their consequences were assessed and then the transport service analysis was finished.

Transport module was used for the analysis and sectors on the roads were located, which was in compliance with other analyses aimed at traffic load. Subsequently the detailed description of traffic accident rate was done in the selected sectors. Transport service on the territory of town is provided on the road network supplemented with the system of railways. Other traffic routes are insignificant. Index of this subsphere is 3,0.

It results from the analysis that it is necessary to slow down the increase of individual car transport and increase the share of public transport. With an increasing number of cars there is an increasing number of accidents and consequently also the increasing number of injuries. There are more serious and light injuries registered on the territory of region as well as in the whole country. It is necessary to implement the measures ensuring the increased security of road traffic. The quality of transport service in the town is good, but traffic security should be increased.

Analysis of the load on town population caused by **electromagnetic field** was focused entirely on electromagnetic fields caused by the operation of mobile network transmitters supporting radio communication among mobile phones. Check measurement of electromagnetic field was carried out around each transmitter in the direction of antennas radiation and in the common residential areas. The measurements proved that acceptable electromagnetic field values were not exceeded and that is why inhabitants were not exposed to over radiation. Index value is 1,9.

Polluted surface waters belong to external factors, which may have a negative impact on human health. Significant sources of risk for people swimming in natural swimming pools are the toxic cyanobacteria metabolism products. Level of risk for a sensitive person is higher with increasing amount of these micro organisms in water. Two swimming areas frequently visited by the town inhabitants were chosen for the surface water quality analysis. The analyses were made at the beginning, in the middle and at the end of the swimming zones. The following criteria were decisive for the assessment of possible source of health risk: the level of microorganic contamination, indicators of chemical contamination and the degree of biological activation of water in both locations. Chemical contamination is within limits and also the amount of cyan bacteria and their toxins do not indicate a fundamental health risk for people at recreational reservoirs. Index 0,8 corresponds to the above mentioned low level of risk.

Long-term monitoring of **drinking water quality** proved that all the required criteria are met (Ministry of Health, 2004). All the quality criteria do not exceed the limits in the long-term, both in the sources and in the monitoring checking profiles on the net. The group of four trihalogenmethanes as possible by-products of disinfection of water by chlorine gas was monitored as risk indicator. The sum of their volume did not exceed the limit value of 150 $\mu g.dm^{-3}$. Despite this fact the risk assessment was carried out for the life-long intake of drinking water from water pipes due to significant potential non-carcinogenic and carcinogenic effects of the above mentioned substances. The assessment was made for three groups of population newborns and infants, pre-school and school age children, and adults. With respect to the exposure scenario for the intake of trihalogenmethanes in inhalation and dermal ways it is possible to consider the health risk arising from the long-term using of drinking water from the water pipes as insignificant and index value 2,2 corresponds to that.

Analysis of **food and its health quality** was focused mainly on animal raw materials. Twelve selected micro organisms were monitored in relation to microbial risk. Samples on usual extraneous substances in food chain were examined and over-limit findings were recorded. It results from the analysis that food quality in the region is the same and often even better than the average in the Czech Republic. 2 - 3 % of examined samples did not meet the sanitary regulations microbially.

Bacteria of Salmonella represent the highest risk for the consumers of animal food. Salmonellae were found mostly in the meat products, eggs and egg products, which were not heat-treated. As the samples of non-heat-treated meat products were examined before delivering to the market the risk of alimentary disease is less likely in case of this commodity. Alimentary infection is more likely in the commodity of eggs, especially due to the wrong storage and treatment. It creates conditions for massive propagation and further contamination and causes consumers´ infection.

Listeria moocytogenes does not currently represent a significant risk for the consumers in the town. It was isolated in six dairy products in Moravia region, including imported goods (cheese from Germany), and in an intermediate meat product. From 1998 to 2000 it was detected 12x on the territory of Moravia, mainly in dairy products. The occurrence was scarce in the other years. Beta hemolytic streptococcuses were isolated sporadically, mainly from milk or dairy products and infection risk is minimal. The situation can be assessed analogically in case of the other pathogenic and conditionally pathogenic micro organisms. Health risk of extraneous substances in the other components of food chain was not significant either.

Index 2,8 was calculated according to formula (2) after risk assessment of both food quality groups.

Soil is one of the environmental elements deserving special attention due to contamination. Many negative factors (traffic, industry) accumulate in towns and have a significant negative impact on the **quality of soil**. Increased contamination of soil surface from toxic metals and persistent organic substances in big cities and industrial agglomerations is the source of risk especially for children (Sarkar, 2002). Similar problems exist with microbial contamination of soil surface and dust especially at children playgrounds and recreational areas.

Ten kindergartens in the town were selected for the analysis, in which selected chemical elements, organic pollutants, microbial and parasitic contamination were assessed. Consequently the risk assessment arising from contamination was made in pre-school facilities. Monitored locations equally cover the area of the town. Exposure of children to harmful elements and resulting health risks were the parts of the analysis.

From the acquired data on soil it was found out that the determined A criterion was exceeded only in two cases. The total volume of polycyclic aromatic hydrocarbons exceeded this criterion in all locations. B criterion was not exceeded not even in one case. When the B criterion is exceeded it is considered to be pollution, which can have a negative impact on human health and the health of the environmental elements and requires preliminary risk assessment. The risk of non-carcinogenic impact resulting in the damage of health orally was not proved.

Based on the presented outcomes the risk index value for this subarea was assessed to be 3,1.

Waste management analysis was focused on municipal waste and its dangerous elements. Household biowaste, dead animals and excrements (dogs, cats, and pigeons) are especially risky. Another risk is caused by illegal waste dumps, especially if they contain dangerous components such as oils, paints, heavy metals, pharmaceuticals, etc. These dumps are potential sources of contamination for surface and subterranean waters. There were cca 28 illegal dumps at the time of analysis. Illegal incineration of waste in local furnaces or at the open fireplaces causes risk, too. Incineration of waste containing organic chlorine and fluorine is highly dangerous, because they are the sources of polychlorinated or polyfluorated biphenyls, dibenzo p dioxines, dibenzofurans, phosgene and other pollutants. Situation in the subarea of waste management was assessed by index 3,5.

A questionnaire was compiled in order to collect information connected with **children accident rate** including number, reasons, circumstances, types and locations of accidents. The outcomes were similar to national average as far as the seriousness, frequency; time and place of accident are concerned. Many children are injured at schools and especially during organized sport activities at schools. We can speculate about a high numbers of children in gyms and their low flexibility, which might be caused by unsuitable lifestyle. Children are afraid of movement and increasing number of them is also overweight. Frequency of accidents on bikes is slightly higher in the suburbs than in the town centres. Risk index is 3,4.

Data from 112 business enterprises in the town were assessed in the analysis of the **quality of workplace**. The analysis proved that the highest number of employees in hazardous jobs work in noise over the limit of 85 dB. The second factor is dust followed by chemical substance and vibrations. Men are exposed to risk factors at workplaces more than women except for the factor of physical load, where only women working in the electrotechnical industry were chosen due to the asymmetric stress placed on upper limbs. Women are also more exposed to biological factors. Health risk index of the assessed subarea has got the value of 3,2.

Industrial and urban zones are mixed up in the region and there are also complicated road transport routes, which often go through areas with high density of settlement. Besides predominating food industry there is also heavy industry, chemical factory, number of petrol stations and other facilities treating dangerous substances. That is why it was decided to assess and prioritize the **technological risk**. There were 120 enterprises chosen as possible sources of the risk on the territory of town. The sources were subjects to risk analysis with the method developed by IAEA (International Atomic Energy Agency, 1993). Both stationary and mobile sources of risk were assessed.

Tab. 1. The health risk indexes and weight values set for monitored subareas

Assessed area	Assessed subarea	Index	Weight
Health and environment	Non-infectious diseases	4,0	0,10
	Infectious diseases	2,9	0,07
	Zoonoses of the region	1,1	0,05
	Noise pollution	2,6	0,05
	Air quality	3,6	0,12
	Traffic accident rate and transport service	3,0	0,06
	Electromagnetic field load	1,9	0,04
	Quality of surface waters for recreational use	0,8	0,02
	Quality of drinking water	2,2	0,11
	Food and its health and quality	2,8	0,11
	Quality of soil in kindergartens	3,1	0,08
	Waste management	3,5	0,06
	Injury rate of children and young people	3,4	0,07
	Quality of workplace	3,2	0,06
Technology	Break down, accidents	3,7	

Fixed sources having been assessed are mostly in category of acceptable risk. The risk of other sources can be reduced on an acceptable level by introducing technical and organizational measures. Only ice-skating rink poses unacceptable risk due to its obsolete cooling equipment and the location in the town centre. Risk posed by mobile sources is also significant and it is necessary to minimize it immediately, e.g. by diverting part of road transport off the densely populated areas. By accepting the above mentioned facts and the assessed risk values of individual sources it is possible to classify this subarea by index value 3, 7.

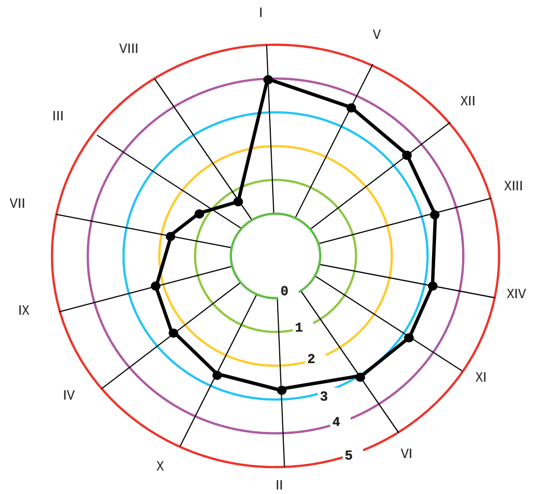
The acquired outcomes together with the weight values set for individual subareas are summarized in tab. 1 and graphically illustrated in Fig. 1.

Total health risk index for the region is 2,9. It was calculated with formula (3). Total index for technological and health risk was acquired by applying formula (4). The index is 3,3 under the assumption the assessed areas are of the same significance.

The implemented risk assessment revealed problems in the structure of health risks, assessed the level of technological risk in the region and supported competent administrative authorities in their decision making process. The analysis proved that the most risky subareas from the sphere of health risk are the following ones: non-infectious and mainly carcinogenic diseases, quality of air, waste management, injury rate among children and last but not least, area of technology. The assessed index value of technological risks significantly exceeds 3,0 and requires immediate measures to be taken. For the proposal and selection of measures it is recommended to use scientific methods. While selecting an alternative it is good to consider its effectiveness (whether we reach the required objectives), costs, feasibility and impacts on life in the region.

Although measures were proposed to improve the situation and reduce risk in all monitored subspheres, especially in those with the index value over 2,5, only the measures for the most risky spheres of life in the region are mentioned below:

a) Prevention of smoking and activities aimed at improving eating habits and life style were proposed with respect to high occurrence of chronic non infectious diseases. At present time a team of experts is built. The subject matter will be discussed and possible procedures will be proposed by the team.
b) Multidisciplinary conference is being organized. It will be focused on nourishment and other factors affecting and preventing colorectal carcinoma.
c) Educational programmes for public were developed. The programmes were used for purposeful intervention in the area of health support. Public is permanently informed about the principles of healthy lifestyle through mass media.



I - non-infectious diseases; II - infectious diseases; III - zoonoses of region; IV - noise pollution; V - air quality; VI - traffic accident rate and transport service; VII - electromagnetic fields; VIII - quality of surface waters from the recreational viewpoint; IX - quality of drinking water; X - food and its health and quality; XI - quality of soil in selected kindergartens; XII - waste management; XIII - injury rate of children and young people; XIV - quality of workplace
0 - negligible risk; 1 - marginal risk; 2 - acceptable risk under the limit level; 3 - tolerable risk, which should be gradually reduced; 4 - significant risk over the level of current standards, which should be minimized immediately; 5 - risk is unacceptable

Fig. 1 Health risk indexes of the monitored subareas

d) Changes of transport system are proposed, by-pass of the town is under construction, quiet zones are established, carrying capacity of vehicles going through the town are being reduced, etc.
e) The state price policy in the field of energy will play an important role as well. It should reduce the consumption of solid fuels.
f) Tutorial classes are organized on the municipal waste management with focus on dangerous components, utilizable parts of waste, biologically degradable waste, waste incineration at local furnaces or in open area and its negative impacts. At the same time citizens are informed about the above mentioned topics by mass media.
g) Environmental Department decontaminates the illegal waste dumps containing dangerous components of waste. New system of payment for the municipal waste disposal was proposed as a preventative measure aimed against creating uncontrolled waste dumps.
h) System of separated biowaste collection from households is being prepared. Litter bins with polyethylene bags are introduced in the town. There are two exhausters for dogs´ excrements in the technical equipment of the town.
i) Information materials are developed for children and their parents and teachers. They are focused on the prevention of injuries.
j) Detailed research of soil contamination and identification of pollution sources continue. Special attention is paid to microbial and parasitological assessments. At the same time risk assessments are developed for the intake of inhalations perorally and dermally with focus on organic substances with carcinogenic impact and selected heavy metals, especially lead, mercury and arsenic.

Conclusion

It seems to be rational to organize risk monitoring with the aim to improve information basis and support sustainable development of the region. Index method was proposed for the needs of administrative authorities. This method enables to compare vulnerability of regions in various areas and at the same time compare various regions.

Procedure in the system risk analysis is based on the fact, that data acquired on the basic level by direct measurements, calculations, expert assessments, or sociological research are transformed into non-dimensional indexes. Next, the partial integrated index of i-level is gradually determined as a weighted sum of indexes of lower (i - 1) levels. Indexes of i-levels are then the bases for the indexation of (i + 1) levels of the assessed areas. It means that a hierarchical structure of indexes is built in each of the monitored areas. Complex integrated index is a weighted sum of marginal indexes describing different security aspects.

The proposed method enables the assessment of the region security level. It is based on using a large number of critical indicators, which reflect the risk from various spheres of human activities. The method also enables to determine the risk priorities on individual levels, or areas within the assessed hierarchical structure. Exactness of risk being classified on the basic level and the extent of assessment depends on the intentions of management authorities.

The proposed methodology was verified for the areas of health, environmental and technological risks with the exploitation of the AZER project outcomes (Vomacka, 2002). Fourteen health risk subareas altogether were assessed in the selected

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region. Partial and then complex integrated indexes were determined in these subareas. Based on the acquired index values the following areas were proposed to have a high priority: non-infectious diseases, air quality, waste management, injury rate of children and young people. It was proved that the sphere of technological risks also deserves attention of administrative authorities.

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